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Field Experiments on Mechanical Double-skin System of Room-side Air Gap in a Residential House

Kan Lin[a], Shinsuke Kato[b]

[a]*The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo, Japan*
[b]*IIS, The University of Tokyo, 4-6-1 Komaba, Meguro-Ku, Tokyo, Japan*

Abstract

One common type of Japanese houses is detached residential wooden house. The wood components within a wall may undergo decay because of condensation in the wall or flushing defects. A double-skin system of room-side air gaps is considered to be an effective technique to handle these problems. In this system, during the summer, the airflow driven by mechanical ventilation moves through the room-side air gap in the wall and removes heat load from the inner surface of the insulation material. In this research, a field experiment was conducted in a two-story residential house in Tokyo of Japan in the summer. The basic properties, temperature distribution and thermal performance have been measured during the summer period. Result shows that the mechanically double-skin system reduces the temperature of double-skin space by 1 °C.

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Keywords: Double-skin system; Experiment; Residential House; Mechanical ventilation

1. Introduction

Wooden detached houses, which have wood-based structural insulation materials for walls and flooring, are widely used in Japan. However, many problems exist with this type of home construction. For example, during the summer period, incoming solar radiation is not equally distributed, leading to uneven indoor temperature distribution. In the winter period, indoor humidity is closely related to the durability of the building envelope. Moisture leaking from the interior rooms increases the risk of condensation on the walls, because the surface temperature of the wall is low. Condensation on the walls may cause the wood used in the houses' construction to decay. In addition to condensation from interior rooms, water vapor condenses on wooden window frames, and rainwater can leak through the roof and walls. The increased moisture is absorbed by the wooden structure of the house, and reduces the endurance and strength of the wood, and also accelerates its decay.

* Corresponding author. Tel.: +81-3-5452-6434; fax: +81-3-5452-6432. *E-mail address*: mystlin@gmail.com

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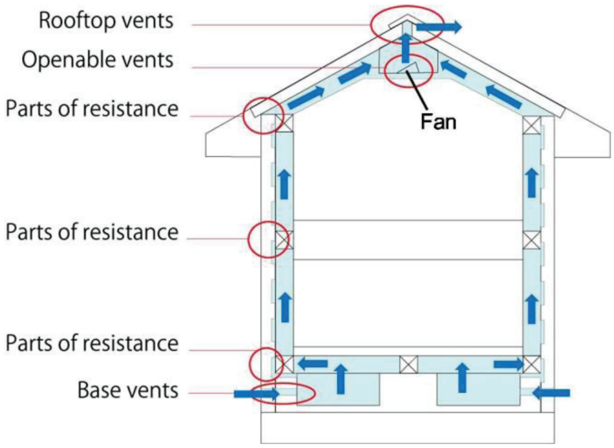

Fig. 1. Outside view and ventilated wall of the experimental house: (a) outside view, (b) Ventilated wall.

To remove the moisture between the external and internal walls, a double-skin system is commonly installed to detached houses. A double-skin system consists of a multi-layered facade, with a buffer space used for ventilation. Air flow in the ventilated wall is controlled by ventilation fans set on the loft. This system can integrate the mechanical ventilation with natural ventilation so that air can move freely in the buffer space.

In summer, air vents in the basement are opened and the ventilation fans in the loft are turned on to facilitate airflow through the ventilated wall, and out the roof. Airflow in the ventilated wall removes heat from solar radiation and from the internal wall. The airflow discharges heat in the wall and attic space, while obtaining cold heat from the ground under the floor. This ensures that the rooms are kept in moderate temperature and comfort.

Although houses using this system have been built for about 30 years in Japan, only a few studies have been conducted on them. Ballestini [1] presented the double-skin system has gained popularity in prevalent time for reducing solar heat gain in buildings. Chow [2, 3] claimed that glass facades have the ability of saving a large amount of energy in winter because these materials reduce both heating costs and illumination by getting the most use of solar energy and day light. Gratia [4-8] evaluated the natural ventilation of the double-skin facades that is influenced by both wind force and buoyancy force. He also evaluated the effects of sensitive factors that affect double-skin facades such as building orientation, and wind direction. Using a simulation of a model house from previous research, Ozaki [1] analyzed the airflow speed in the wall, as well as the airflow in the space under the floor during the summer period.

For office buildings, a few studies have been conducted as well. Poirazis [9] presented examples of office buildings with Double Skin Facades and fields of further research. In an office building of with the floor area of 3775m^2 and height of 13 m, Oka [10] measured energy conservation performance during summer period. Hensen [11] conducted a study on the energy saving effect of double skin system in a 8-stories building, and confirmed that nearly 15% cooling load from 2F to 8F could be cut down in summer. The conclusion is that the lower stories have much larger energy saving effect in summer. Ito [12] measured the thermal environment in a 7-story public building with the floor area of 2933m^2 and height of 37 m. Matsushima [13] made a study in an office building with the floor area of 8048m^2 and height of 58m, and estimated that there is a potentiality of 240 Gcal for annual energy consumption which could be cut down.

However, there is hardly any information available regarding the actual airflow and thermal effects of this system in a residential house. For this reason, it is difficult to select appropriate strategies to maintain airflow rate in the ventilated wall in a residential house.

The objective of this study is to understand the basic properties of the double-skin system, temperature drop, during the summer period by performing a field experiment. The field experiment was conducted in a two-story residential house in Tokyo of Japan in the summer. The basic properties, temperature distribution and thermal performance have been measured during the summer period. The results show that natural indoor temperature drop effects were significant when the mechanically double-skin system was used.

2. Outline of field experiments

The experimental house which is located in Tokyo is a two-story residential house with the floor area of 96m^2 and height of 6.2 m, and it is 5.5m long in the east–west direction and 10.0m wide in south–north direction. Its outside view is shown in Fig. 1(a), and the air gap in the ventilated wall is shown in Fig. 1(b). The details of the air gap in which air moves upwards is represented as the blue portion. Grooves are arranged on the surface of the insulation material in equal intervals. These create openings between the insulation and the other components, so that air flows freely. The air gap is divided into several zones by resistance parts, such as vents or other openings. In such zones, the flow path is narrower than the open air gap. The properties of the experimental house in this study are listed in Table 1.

The field experiment in summer was conducted from August 21 to September 9 in 2014. All the data are recorded by data collectors and the distributions of measurement points are shown in Fig. 2. To estimate effects when ventilation fans are turned on, the ventilation fans of the basic case (Case 0, 8/21-8/22) is closed, and the flow rate of the other case is set to 630 m^3/h (Case 1, 9/5-9/6). In the case 0, the air-conditioning period is set to 8:00-20:00 on 8/21 and 9:00-21:00 on 8/22. The air-conditioning temperature is set to 28°C and the only air-conditioning is set at the top of second floor.

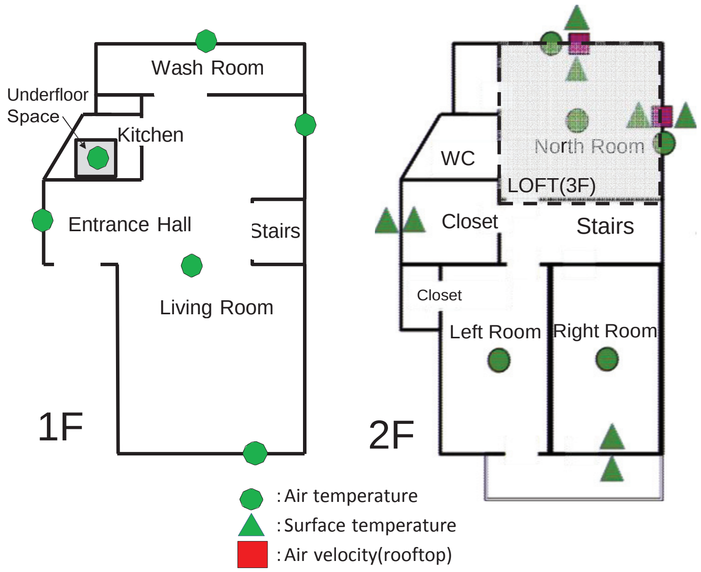

Fig. 2. Measurement details

Table 1: Building Properties [14, 15]

Wall of external side	Extruded polystyrene foam = 50 mm + Air layer = 15 mm + Tile = 10 mm
Wall of internal side	Gypsum board = 13 mm
Air gap thickness	120 mm
Roof	Extruded polystyrene foam = 50 mm + Air layer = 30 mm + Plywood = 10 mm + Slate = 5 mm
Base	EPS 50 mm + RC 150 mm + EPS 50 mm
Internal wall, Ceiling, Floor	U = 3.125 W/m^{2}K, 4.082 W/m^{2}K, 4.082 W/m^{2}K
Window	U = 1.8 W/m^{2}K

3. Experiment results

3.1. Case 0, Fan OFF

Figure 3 shows the results of the indoor temperature and solar radiation during representative days for case 0, in which the airflow rate of ventilation fan is 0. The average outdoor air temperature is 30.2 °C with the maximum of 33.7 °C and the minimum of 26.3 °C. The temperature of under-floor space is stable at 27 °C because outdoor air cannot influence the temperature of under-floor space.

The temperature of the 1st floor drops to 28 °C after 8am because the air-conditioning is working. The temperature in the loft changes more drastically than other indoor temperatures, and the temperature reaches as much as 31°C after the air-conditioning stops.

Figure 4 shows the results of surface temperature during representative days, in which the airflow rate of ventilation fan is 0. The surface temperature of outer walls is extremely high, which reaches the maximum of 44 °C both on the south wall and the west wall because solar radiation influences the surface temperature effectively. The surface temperature of south inner wall reaches as much as 31 °C and the surface temperature of west inner wall reaches the maximum of 29 °C. The surface temperature of under-floor is stable at 26.5 °C

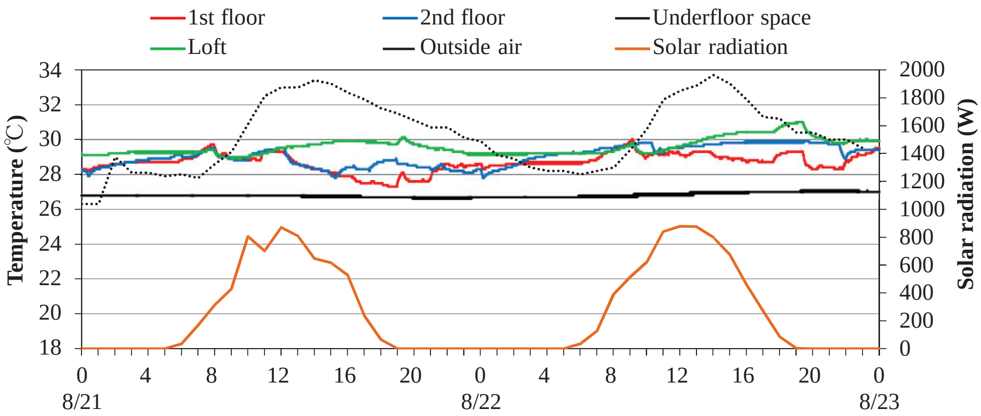

Fig. 3. Indoor temperature and solar radiation during representative days (Case 0, Fan OFF)

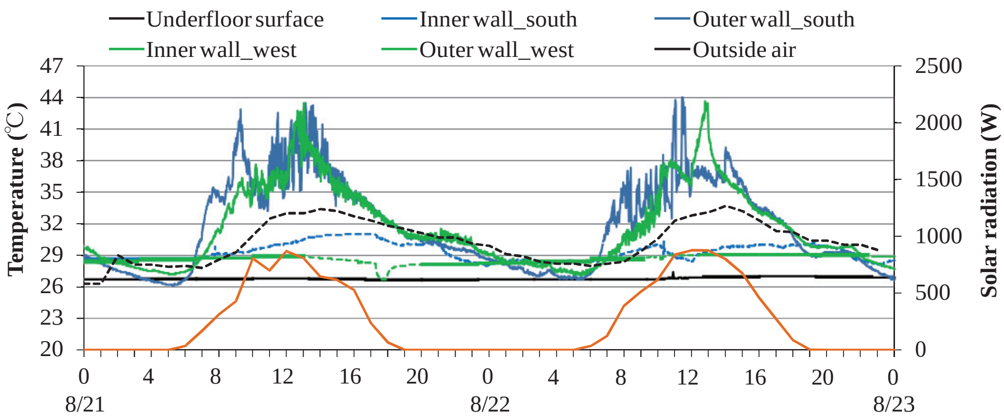

Fig. 4. Surface temperature and solar radiation during representative days (Case 0, Fan OFF)

3.2. *Case 1, Fan ON*

Figure 5 shows the results of the indoor temperature and solar radiation during representative days for case 1, in which the airflow rate of ventilation fan is set to 630 m^3/h. The average outdoor air temperature is 28.1 °C with the maximum of 32.0 °C and the minimum of 23.7 °C. The temperature of under-floor space rises from 24 °C to 26 °C because the outdoor air from outside is cooled down when it goes though the under-floor space. Although the air-conditioning is turned off all day, the temperature of loft rises to 30°C, and the temperature of 1^{st} floor rises to29 °C.

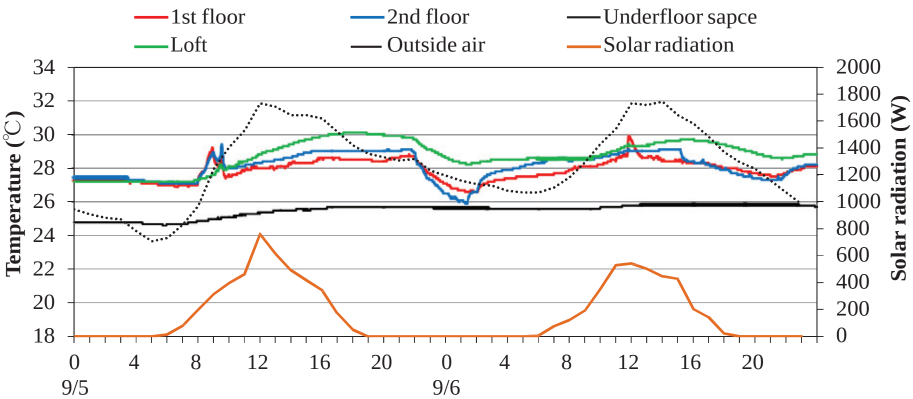

Fig. 5. Indoor temperature and solar radiation during representative days (Case 1, Fan ON)

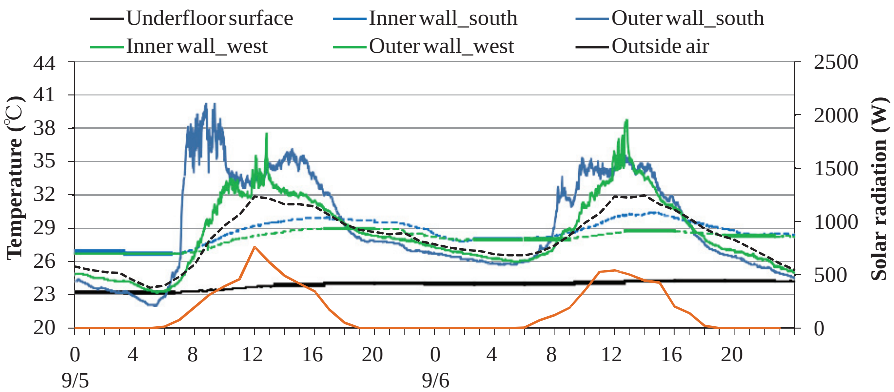

Fig. 6. Surface temperature and solar radiation during representative days (Case 1, Fan ON)

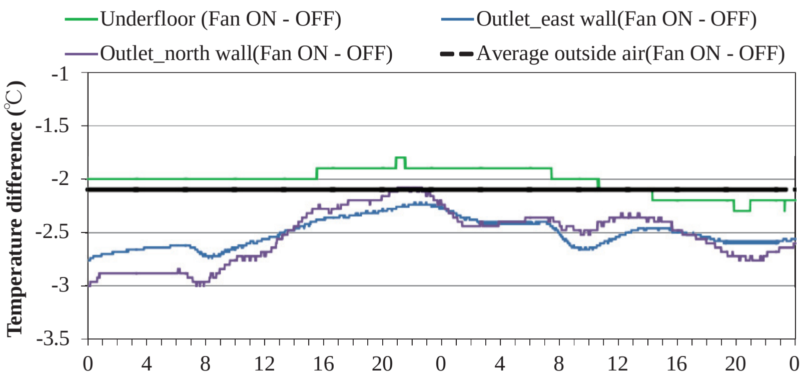

Fig. 7. Temperature difference between Case 0 and Case 1 during representative days

Figure 6 shows the results of surface temperature during representative days, in which the airflow rate of ventilation fan is set to 630 m^3/h. The surface temperature of outer walls is high, which reaches the maximum of 40 °C on the south wall because solar radiation influences the surface temperature effectively. The surface temperature of south inner wall reaches as much as 31 °C and the surface temperature of west inner wall reaches the maximum of 29 °C. The surface temperature of under-floor is stable at 26.5 °C

Figure 7 shows temperature difference in each air gap zone between Case 0 and Case 1 during representative days. The average temperature difference of outside air is 2.1 °C. Temperature decreases in every air gap zone from 3 °C to 2 °C with the maximum of 3.0 °C in the outlet of north wall. The temperature difference of under-floor space is less than the average temperature difference of outside air because the outdoor air from outside is cooled down when it goes though the under-floor space.

4. Conclusions

In this research, a field experiment was conducted in a two-story residential house in Tokyo of Japan in the summer. The basic properties, temperature distribution have been measured during the summer period. When the mechanical fan is turned on, cooling is improved as the outdoor air from outside is cooled down when it goes though the under-floor space. And heat from solar radiation and internal heat in the double-skin space can be discharged by mechanically fan.

According to the results of the experiment, it can be concluded that in summer, the temperature reduction effect is significant because the mechanically double-skin system reduces the temperature of double-skin space by the air which is cooled by under-floor space, in which the airflow rate of ventilation fan is set to 630 m^3/h. In addition, figure 4 and figure 6 show that during the daytime when sunlight is very strong, the outer surface temperature reduces by the air from under-floor space.

According to the above analysis, the mechanically double-skin system is proved to be energy effective for residential houses in summer. And air-conditioning settling time can be reduced by the temperature drop effect.

To evaluate the effect of cooling load, a simulation that considers infiltration between the interior-exterior wall interface and between the wall-room interfaces is needed in future.

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